The Impact of Color-Coded Sustainability Infographics on Short-term Memory

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ABSTRACT

This paper explores the impact of color relationships on short-term memory and its potential to enhance the retention of complex concepts, such as sustainability-related information. By using the United Nations' Sustainable Development Goals (SDGs) and their color-coded infographics, this project evaluates the effectiveness of color relationships in enhancing short-term memory. To assess the effectiveness, a simple yet engaging memory game has been designed. The game employs a flipping flashcard format, where each card features two sides: the front, which displays symbols of the SDGs, and the back, which contains corresponding textual information. Ultimately, by calculating and comparing the accuracy rate of participants' answers in each round of memory games, this project concludes that complementary color pairs have a subtle positive impact on enhancing the recall of sustainability-related information

1. INTRODUCTION

The relationship between visual perception and memory has been a subject of interest, with numerous studies examining how different visual stimuli, particularly color, can influence memory retention.

Previous research has shown that using similar colors can enhance short-term memory and emphasize its practical applications in diverse fields such as education, design, and user experience (Sanocki & Sulman, 2011). Also, a biology researcher Kai Ling Abang stated that "colors serve as powerful visual markers, breaking down complex information into more digestible chunks and preventing cognitive overload" (Anki Pro, 2024).

Thus, understanding the role of color in memory is crucial for enhancing communication, especially when it conveys complex concepts (Dzulkifli & Mustafar, 2013). Sustainability-related topics, for example,

are often challenging for individuals to comprehend and retain. For this, the United Nations introduced the 17 Sustainable Development Goals (SDGs) and assigned a distinct color to each goal to facilitate easier processing of the information. This paper investigates how such information is affected and remembered through the use of color grouping. Building on this foundation, we aim to provide valuable insights into the effectiveness of color relationships – harmonious and complementary – and short-term memory, specifically in the context of complex sustainability information.

2. BACKGROUND

2.1. The SDGs

Sustainability-related information often involves intricate concepts and large datasets. To address this, the United Nations developed the 17 Sustainable Development Goals (SDGs) as infographics and assigned a unique color code to each goal (figure 1) (UN DESA, 2020). The color coding visually segments the goals and explains them with symbols, making them easier to process.

Figure 1. Sustainable Development Goals

However, despite these efforts, many people struggle to remember sustainability-related information. One possible reason could be the large number of goals, which exceeds the cognitive limit of remembering 4 things in working memory at a time (Weinschenk, 2011). Additionally, using distinct colors for each goal and distributing them without categorization may make short-term retention more difficult.

2.2. Short-term memory

A study by Cascella and Al Khaili (2024) defines short-term memory as primary or active memory, which involves the temporary storage of information, typically lasting up to 30 seconds. They note, "The term refers to different memory systems that retain pieces of information, or memory chunks, for a relatively short period, whereas long-term memory can store information indefinitely" (Cascella & Al Khalili, 2024).

Humans have a limited amount of working memory. It makes it challenging for someone to simultaneously hold a large amount of information. Chunking is a strategy that overcomes this limitation by grouping individual pieces of information into more manageable units. According to research by Thalmann et al. (2019), chunking decreases the load on working memory. This allows efficient information processing and improves overall cognitive performance.

2.3. Aims and delimitations

We aimed to explore how sustainability-related information, specifically SDGs infographics, can be delivered more effectively by leveraging effective color combinations and short-term memory. We used complementary colors, which are opposite each other on the color wheel (figure 2), and harmonious colors, which are adjacent on the color wheel, to design the infographics (figures 3 and 4).

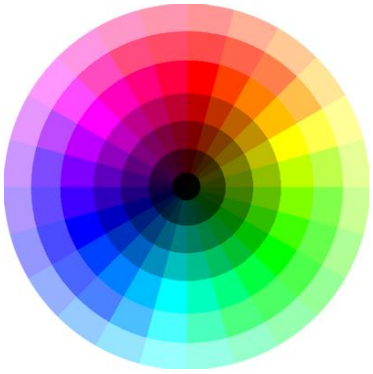

Figure 2. The color wheel

Figure 3. Complementary colored infographics

Figure 4. Harmonious colored infographics

To isolate the impact of simultaneous colors on short-term memory, we are eliminating the numbers on each SDGs card and maintaining consistency in other elements, minimizing the information, maintaining the icons, and maintaining the consistency of the color of the font and symbol on each SDGs card.

This approach ensures that our experiment focuses solely on the crucial information and color combinations in enhancing short-term memory about sustainability-related topics.

While this study examines how colors affect short-term memory, we hope to inspire meaningful learning experiences that encourage long-term retention of sustainability-related information and promote sustainable behaviors in daily life.

2.4. Research question

How does harmonious or complementary color-coding impact short-term memory retention, when applied to complex sustainability information?

3. METHOD

We combined qualitative data, such as pre- and post-interviews, and quantitative data, such as memory questions about the SDGs cards.

3.1. Hypothesis

This study investigates the influence of color-coded infographics on memory retention, specifically comparing complementary and harmonious color combinations. The following statistical hypotheses were formulated:

Null Hypothesis (H_0): There is no significant difference in memory retention between participants exposed to complementary color combinations and those exposed to harmonious color combinations.

Alternative Hypothesis (H_1): Memory retention significantly differs between participants exposed to complementary color combinations and those exposed to harmonious color combinations.

3.1. Participants

The study targeted participants aged 18 to 65+, representing the general public while excluding professionals in sustainability to avoid potential bias. In total, 20 participants contributed to the study. Efforts were made

to ensure a balanced gender representation, promoting diversity in responses. Participants were familiar with the Sustainable Development Goals (SDGs) through exposure to related content but had not previously engaged deeply with them. Only individuals with normal color vision were included to ensure accurate interpretation of visual elements, which was ensured through color-blindness tests. Most participants were recruited either on campus or through common contacts.

3.2. Data collection

The data collection was conducted through a series of pre-interview, experimental, and post-interview phases.

3.2.1 Pre-interview

As a method of pre-screening, a Google Form was given to each participant. The form consisted of three background questions and four key questions, summarized in table 1. These were asked to gather relevant information about the participants and to ensure they were eligible to conduct the test. Then, we screened the participants using the Ishihara and Farnsworth D15 color blindness tests.

Category	Question Number	Question
Background Questions	1	Age Range? a. under 18; b.18–24; c.25–34; d.35–44; e.45–54; f.55–64; g.65+
	2	Do you have experience of working professionally in the sustainability domain?
	3	If you're comfortable, can you please share your pronouns (e.g., she/her, he/him, they/them, etc.)?
Key Questions	4	How familiar are you with sustainable development goals? Can you describe all the SDGs that you remember?
	5	Do you use corrective lenses or have any vision impairment that might influence your color perception?
	6	Can you identify the numbers displayed in Ishihara test?
	7	What result did you get from the color arrangement test? a. Normal b. Protanopia c. Protanomaly d. Deuteranopia e. Deuteranomaly f. Tritan Defects

Table 1. Pre-interview Questions

3.2.2. Flipping card interface

The website served as the study's platform (appendix 1). Participants were first presented with a consent screen to ensure they understood the purpose of the study and consented to their information being used. After, participants were split and assigned to one of two quizzes: Quiz 1 or Quiz 2. In both quizzes, participants were presented with two cards, each featuring a front and back side with information about a Sustainable Development Goal (SDG). The front side displayed the SDG's icon, while the back side provided the title of the SDG along with some information about its topic (appendix 2). The cards were color-coded

and paired with other cards that were either complementary or harmonious. However, the pairings of the cards differed between the two quizzes.

3.2.3. Experiment

This study employed a within-subjects design with randomized order of card pairs for each participant to minimize order effects. The experiment was structured into six rounds, as described earlier, where participants were presented to color-coded cards featuring information of different SDGs. Each round lasted 30 seconds, during which participants were instructed to observe the cards and take in as much information as possible.

After each round, participants were required to fill out a response sheet created in Google Docs. For this stage, the participants had 60 seconds to recall and fill in the information from the cards, including its symbol, title and description. By the end of the last round, each participant was exposed to both complementary and harmonious color card pairs.

3.2.4. Post-interview

At the end of the experiment, participants were asked several questions regarding their test, summarized in table 1. The post-interview was conducted to gain insights on the complexity of the test and to understand what the participants perceived as helpful for recalling information. They were then asked to explain why they thought those elements were helpful. Finally, participants were asked to provide additional factors they believe could help improve memory retention. The post-interview does not affect the results but is meant to help us reflect on the test and better understand the participants.

Question Number	Question
1	How difficult do you think sustainable-related information is to remember in general, on a scale of 1 (not difficult) to 5 (highly difficult)? Why?
2	Compared to the SDGs infographic, does color coding help you remember the intricate information better? Why or why not?
3	Which color combination cards do you think improve memory retention? Why?
4	Which one was easier to remember the information? colors or icons? • If the participant chooses icons: Is the black and white icon enough for you to remember the SDGs information?
5	What other factors affect memory retention? (e.g., interface, layout, size, number of cards)

Table 2. Post-interview Questions

3.3. Data analysis

To understand the pattern of participant's memory recall from each color combination card, we calculated the mean and median of the number of items correctly recalled by each participant. Recalling the icon gave one point, recalling the title gave one point, and recalling keywords gave a maximum of two points, one for each correct keyword. This sums up to a maximum of four points per card. These points were then used to analyze the answers.

3.3.1. Symbol accuracy

The percentage of correct symbol/icon recalls for each participant was calculated by dividing the number of correctly identified symbols ($S_{correct}$) by the total number of cards in all six rounds ($S_{total} = 12$) and multiplying by 100.

$$S\ (\%) = \frac{S_{correct}}{S_{total}} \times 100$$

The sequence in which participants recalled the symbols was not considered in this analysis.

3.3.2. Title literal accuracy

This calculation was performed to determine the proportion of textual information that was correctly recalled for each Sustainable Development Goal. Prior to analyzing the title accuracy, we perform a data extraction from participants' answer sheets. First, all the SDGs' title and participants' answers were transformed into lowercase to maintain consistency. Second, we removed symbols and punctuation to prevent errors due to variations in formatting. Then, we scanned the phrase location in participants' answers using the first word of the correct title phrase. Finally, we checked the exact word-by-word to match with the correct title of SDGs that were shown to the participant.

$$T\ (\%) = \frac{T_{correct}}{T_{total}} \times 100$$

The percentage of correct title recalls for each participant was calculated by dividing the number of correctly identified symbols that were shown ($T_{correct}$) by the total number of cards for all six rounds ($T_{total} = 12$) and multiplying by 100.

3.3.3. Keyword accuracy

To calculate the semantic recall from each participant, we use a keyword-based scoring approach. This approach was done to check whether participants could capture the core concepts represented by the cards in each round.

Before starting the scoring process, we selected two keywords from each SDGs title and official one-liner explanation as shown in appendix 3. In this keyword-based scoring system, each card presented to participants also contains two keywords, resulting in a total of four keywords per round. This aligns with the size of working memory capacity of an individual, which typically handles around four items (Cowan, 2001).

This keyword-based scoring process started with extracting keywords or their synonyms directly from participants' answer sheets. Any symbols or typographical errors are omitted during this process.

$$K\ (\%) = \frac{K_{correct}}{K_{total}} \times 100$$

The percentage of correct keyword recalls for each participant was calculated by dividing the number of correctly identified keywords from participant answer ($K_{correct}$) by the total number of keywords for all six rounds ($K_{total} = 24$) and multiplying by 100.

3.3.4. Combined Accuracy

The combined accuracy was calculated by integrating symbol, title and keyword accuracy into a single composite score. This combination provides a holistic view of the participant's recall performance including visual, literal and semantic memory components.

$$Combined\ Accuracy = \frac{S + T + K}{3}$$

The percentage of combined accuracy was calculated by averaging the individual accuracies of three recall dimensions: symbol (S), title (T), and keyword(K).

4. RESULTS

4.1. Quantitative results

From the quantitative test results, it can be seen that no significant difference was found between complementary and harmonious color combinations in general (figure 5). The combined accuracy value of card pairs with complementary color combinations show an average of 70%, while pairs with harmonious color relations show 66% of combined accuracy.

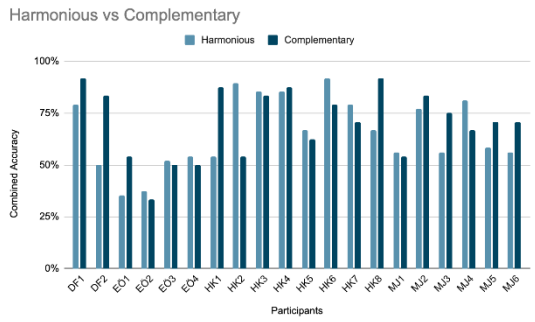

Figure 5. Combined accuracy

Looking closer, there is a difference when it comes to symbol and title accuracy. Complementary color combinations show an average of 96% symbol accuracy, while harmonious color combinations show 95% accuracy. Similarly, card pairs of the complementary color combination performed higher with 50% in average of title accuracy, while it shows 38% for title literal recall in harmonious color combinations (figure 6).

Average	**96%**	**95%**	**95%**
Min	**75%**	**63%**	**75%**
Max	**100%**	**100%**	**100%**
Median	**100%**	**100%**	**100%**

Average	**50%**	**38%**	**42%**
Min	**0%**	**0%**	**0%**
Max	**100%**	**88%**	**83%**
Median	**50%**	**38%**	**50%**

Average	**64%**	**64%**	**64%**
Min	**25%**	**19%**	**25%**
Max	**88%**	**94%**	**88%**
Median	**63%**	**69%**	**69%**

Figure 6. Symbol accuracy (top), title accuracy (middle), and keyword accuracy (bottom)

On the contrary, there is no difference in keyword accuracy. Both color combinations have 64% accuracy on average.

4.2. Qualitative results

The post-interview provided rich qualitative insights into participants' experiences and perceptions during the test. Responses were analyzed and summarized, and key points were taken out.

4.2.1. Color coding for remembering complex information

The responses to whether color coding helps in remembering complex information from the SDG infographic were divided, with 10 participants answering "yes" and 10 answering "no." Those in favor of color coding found it useful for associating goals, improving visual clarity, and aiding recall through familiar associations, such as linking color with specific concepts. However, participants who disagreed felt that the symbols were more helpful for memory, and some found the variety of colors too overwhelming or not strongly connected to the SDGs.

4.2.1. Icons or color?

When answering the question “which one helps you remember the information better?

colors or/and icons?", 11 participants preferred icons, 5 preferred color-coding, and 3 found that both icons and color-coding together helped them remember the information better.

In the responses, the majority favored icons as they were directly related to the information and easier to associate with the content. Many participants felt that well-designed icons were more memorable and intuitive, often forming strong connections with the SDG concepts. Those who preferred color-coding emphasized that it added meaning and distinction to the goals, making them more recognizable. A smaller group found that the combination of both icons and color-coding was most effective, as the colors complemented the icons and enhanced their ability to differentiate and remember the goals.

5. DISCUSSION

In general, no significant difference was found between complementary and harmonious color combinations in terms of their ability to induce sustainability information retention. However, participants recalled titles more accurately when they were shown complementary colors compared to harmonious ones. Many participants highlighted the importance of the icons for their memory.

5.1. Strengths and weaknesses

5.1.1 Colors versus Symbols

To make clear outcomes between color relationships and information, textual information was deliberately minimized in this experiment in this test. However, symbols were included in the memory tests, as they are considered a part of sustainability-related information of SDGs. According to SDGs design guidelines, symbols play a critical role in conveying meaning and enhancing comprehension of the information (UN DESA, 2020). However, this decision may have a notable impact on the study's results and evaluations, as participants seemed to rely more heavily on symbols than color combinations during the memory game. By interacting with these familiar and visually distinctive elements, which are symbols, participants may have found it easier to associate and recall information.

Moreover, color perception can vary significantly across different nationalities due to cultural influences and language differences in color terminology (Madden et al., 2000). Considering the diverse nationalities of participants in this study, these factors may also have influenced the final results.

As a result, the reliance on symbols may have diminished the observable effect of color relationships on short-term memory. This highlights the need for careful consideration of such interactions in future research to isolate and better understand the role of color in information processing.

5.1.2. Interface

According to the post-interview conducted after the memory game, many participants reported that the interface design significantly helped them retain information more effectively. They highlighted specific features such as the clear layout and the limited number of cards displayed on the screen at a time. These elements simplified the cognitive load and allowed participants to focus and process information more efficiently.

In contrast, the SDG infographics present all 17 goals simultaneously, which can be

overwhelming and challenging to process due to the abundance of visual and textual information. The memory game interface (appendix 1 and 2), however, displayed only two cards at a time with minimalized information, which can reduce distractions and make it easier for participants to engage with the content. This streamlined approach appears to have facilitated better information recall and a more focused interaction with the material.

5.2. Mitigating the weaknesses

Conducting preliminary checks for color blindness and familiarity with sustainability-related information proved crucial in minimizing the risks of biased results and ensuring that participants could process and recall the presented information effectively. For instance, one participant was identified as having protanopia, one type of dichromatism with the absence of red-sensitive cone cells (Goldstein & Cacciamani, 2022), which could have significantly influenced their ability to interpret the color-coded materials. As a result, this participant was excluded from further testing to maintain the validity and reliability of the study.

Additionally, assessing the perceived difficulty level of sustainability-related information, particularly when presented in numeric data, provided valuable insights into the challenges participants face in understanding these topics. This evaluation not only underscored the importance of the study but also provided guidance for shaping future research directions. On average, participants rated the difficulty of sustainability-related information as 3.2 out of 5, with 1 indicating “not difficult” and 5 highlighting “very difficult.” (appendix 4). This difficulty level highlights the need for effective communication strategies, such as using color coding and symbols, to enhance comprehension and retention of complex concepts.

5.3. Future improvement

Based on evaluation and discussion, we identified several potential areas for development in future studies.

One key improvement involves refining the design of the memory games to minimize overlapping factors and allow for a more focused analysis of color relationships. To achieve this, two versions of the memory game could be created: one that includes symbols and another without symbols. This approach would help isolate the impact of color on memory retention, as the current study shows that participants tend to rely more on symbols than on color categorization when processing complex information. By controlling the presence of symbols, we aim to produce clearer, more precise outcomes.

Additionally, we plan to modify the interface of the memory game to improve the overall user experience and reduce potential distractions. In the current version (see figure 8), participants must switch between the game interface and an external test sheet (such as a Google Docs), which has been noted by some participants as a distraction that negatively affects short-term memory recall. As one participant mentioned, this shift between windows can disrupt the continuity of their cognitive processing. To address this issue, the future version of the memory game will integrate the memory test form directly into the same interface, allowing participants to complete both the game and the test without needing to navigate away from the primary window. This change is expected to reduce cognitive load

and minimize distractions, ultimately enhancing the accuracy of the results and improving participants' usability.

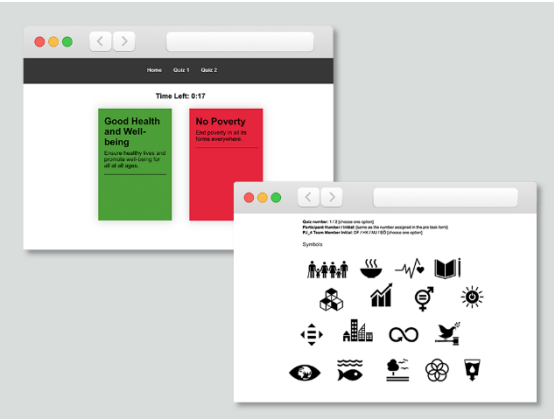

Figure 8. Separate windows for the game interface and test sheet

These improvements will make the study design robust and provide more intuitive insights into how color relationships influence short-term memory retention.

5.4. Learning from previous studies

Previous research on color relationships and memory by Sanocki & Sulman (2011) and Dzulkifli & Mustafar (2013) provided a valuable opportunity to deepen our understanding of how colors serve as powerful visual markers. Also, the study about short-term memory retention by Cascella and Al Khaili (2024) helped us to establish the memory game. Additionally, it was particularly insightful to explore why sustainability-related information is often difficult to recall, despite its importance for the collective good. This gap in retention underscores the need for effective communication strategies to enhance comprehension and memory of complex topics like sustainability.

5.5. Learning outcomes

Moreover, in the process of designing the experiments, we carefully considered a wide range of visual elements, including color, layout, size, font, interface, medium (whether web-based or printed), symbols, and text. Throughout this process, we learned how each visual element contributes to memory retention and understood that the interplay between these factors can greatly influence the effectiveness of information delivery.

Although isolating the most crucial visual elements (and leaving the harmonious/ complementary color condition only) for the memory game interface could have led to clearer outcomes, we managed to reduce the risk of biased results by conducting both pre- and post-interviews with participants. This careful approach not only helped mitigate biases but also helped us gain a deeper understanding of how visual elements can influence memory retention in the context of sustainability-related information.

5.6. Contribution

All members contributed to the initial research on the relationship between colors and memory. Based on this research, the team collectively agreed on the research question and established the experiment setup. Through regular online meetings, both with and without the supervisor, all members actively participated in refining the task design. Each member also took responsibility for conducting individual user tests and successfully collecting data.

Diagnosa Fenomena mainly participated in setting up time management, researching and literature review, designing and establishing the pre-interview form, analyzing

data, data visualization, and designing project slides.

Ediz Özdamar mainly participated in risk analysis, summarizing poster narration, designing and developing the memory web game interface including multiple iterations.

Hyosun Kim mainly participated in developing documents, dividing tasks, researching and literature review, designing and establishing the post-interview form, designing memory test sheets, analyzing future studies, and designing the project poster.

Matilda Jansson mainly participated in researching related works, discovering study setups, designing an experiment checklist, organizing experiment results, post-interview interpretation, and holding the presentation for the supervisor.

6. CONCLUSION

Through this project, we aimed to investigate how harmonious and complementary color-coding impacts short-term memory retention, particularly when applied to sustainability-related information. Looking back at our hypothesis, the results align most closely with our null hypothesis (H_0): 'There is no significant difference in memory retention between participants exposed to complementary color combinations and those exposed to harmonious color combinations.' Our findings contribute to the growing understanding of visual perception and memory by highlighting the potential of color relationships to enhance information recall in complex contexts such as the Sustainable Development Goals (SDGs).

The study demonstrated that participants often relied on symbols more than color combinations, indicating that while color relationships play a role in memory retention, other visual elements like symbols can overshadow their impact. This suggests that future research should focus on isolating these factors to better understand their individual contributions.

We also identified areas for improvement, including refining experimental designs to minimize overlapping factors and creating more seamless interfaces to reduce cognitive load during memory tasks. By addressing these aspects, future studies can provide deeper insights into how color coding and other visual strategies can improve the communication and retention of sustainability-related concepts.

Ultimately, our research underscores the importance of designing effective visual communication strategies to make sustainability information more accessible, memorable, and actionable. This has broader implications for education, design, and user experience, where similar challenges of communicating complex information persist. By leveraging insights from this study, we hope to inspire more effective and engaging ways to promote sustainable behaviors and knowledge retention.

7. REFERENCES

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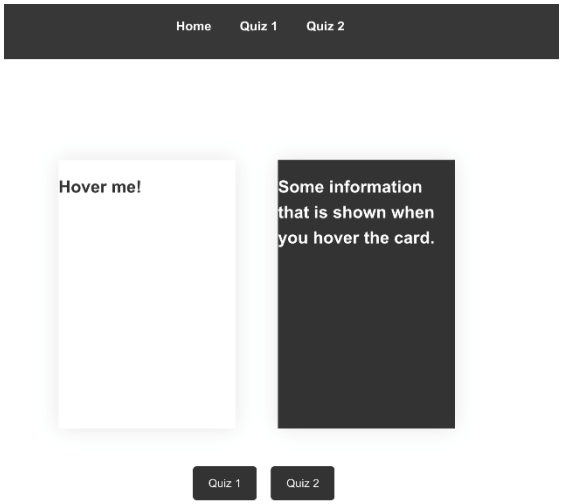
APPENDIX

1. Flipping Card Interface - Tutorial Page



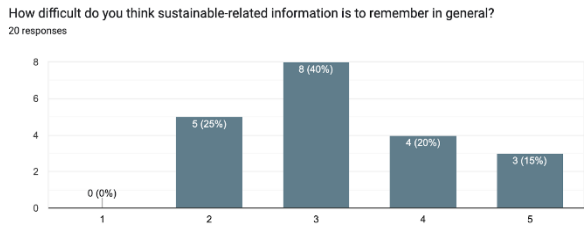
2. Flipping Card Interface - Quiz Page

3. Extracted Keywords From Title and One-liner Official Explanation

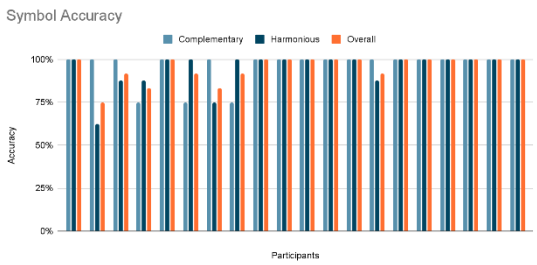
Goal Number	Keywords
1	poverty, equality
2	hunger, nutrition
3	health, wellness
4	education, equitable

5	gender, equality
6	water, sanitation
7	clean, energy
8	decent, economy
9	industry, infrastructure
10	inequality, reduced
11	city/cities, sustainable
12	consumption, production
13	climate, change
14	oceans, marine
15	land, biodiversity
16	peace, justice
17	global, partnerships

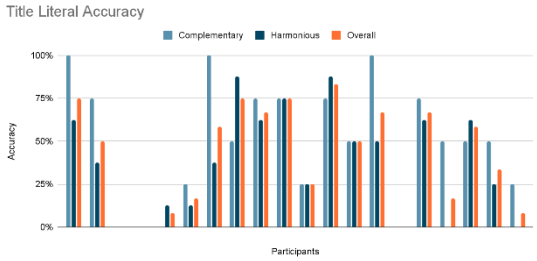
4. Perceived Complexity Level



5. Symbol Accuracy Bar Diagram



6. Title Literal Accuracy Bar Diagram



7. Keyword Accuracy Bar Diagram